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STRUCTURES DUE TO VOLUME SHRINKAGE
IN THE BEDDING-REPLACEMENT FLUOR-
SPAR DEPOSITS OF SOUTHERN
ILLINOIS

By
ROBERT M. GROGAN

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STRUCTURES DUE TO VOLUME SHRINKAGE IN THE BEDDING-REPLACEMENT FLUORSPAR DEPOSITS OF SOUTHERN ILLINOIS.¹

ROBERT M. GROGAN.

ABSTRACT.

Flat-lying, elongate bedding-replacement fluorspar deposits in southern Illinois commonly exhibit structural features best explained as the results of net loss of rock volume during the ore forming process.

Synclines found over many deposits are regarded as the results of a thinning of limestone strata localized in the ore-bearing areas. A statistical study of test borings shows that such localized thinning is a characteristic feature of the district. Also many evidences of subsidence are apparent within the deposits, such as measurable thinning and removal of part or all of certain limestone beds, spalling and collapse of slabs of roof-rock and other layers of rock into the body of the deposits, presence of V-structures, and cavities and tabular openings at the sides and tops of deposits.

The mechanism responsible for the indicated volume shrinkage is considered to be in part the stoichiometric replacement of calcite in limestone by denser fluorite, and in part the actual removal of limestone by the action of solvent mineralizing fluids.

INTRODUCTION.

FLUORSPAR occurs in bedding-replacement deposits in the Cave in Rock district of Hardin County, Illinois, a part of the famous Illinois-Kentucky fluorspar mining field (1, 2, 3, 4, 5).² Prior to 1916 the greater part of the fluorspar produced in Illinois came from vein deposits, principally those in the Rosiclare district. Since that time, however, an increasingly larger share has come from the bedding deposits, as indicated by the fact that during the period 1940 through 1945 they yielded an estimated 42 percent of the total Illinois production. Because of their importance they received special geologic study during and after World War II.

DESCRIPTION OF DEPOSITS.

The bedding-replacement deposits are found in Mississippian limestones at four principal stratigraphic levels that occur within a vertical distance of 190 feet, extending downward from the top of the Renault limestone to about 75 feet below the top of the Fredonia limestone. The deposits are generally elongate and lie essentially parallel to the plane of stratification of the replaced limestones. Single continuous ore bodies have been mined for as much as

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² Numbers in parentheses refer to Bibliography at end of paper.

2000 feet in the direction of their greatest length and 480 feet at right angles to that direction, although widths of 50 to 200 feet are more common.

Fluorspar is the chief ore mineral, but sphalerite and galena are also of major importance in several deposits. Common accessory minerals include calcite, quartz, barite, chalcopyrite, marcasite, and pyrite. Most of the fluor-spar occurs as banded replacement ore in distinct beds that range from a few inches to 3 feet or more thick. Where two or more ore beds are present they

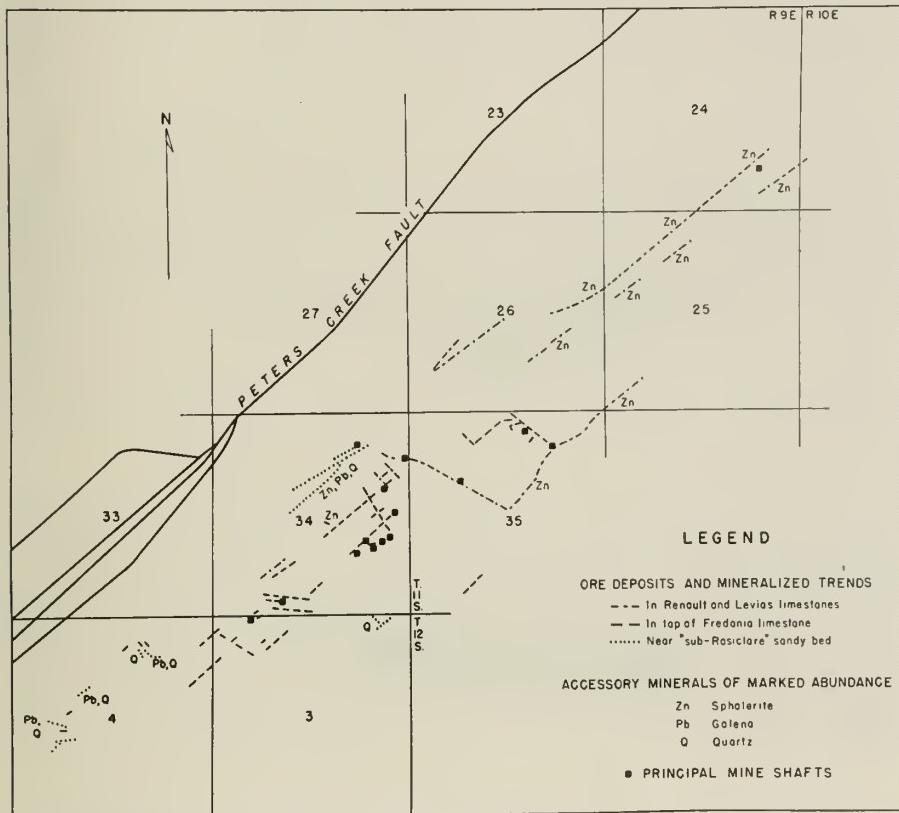


FIG. 1. Principal deposits and mineralized trends, Cave in Rock fluorspar mining district, Hardin County, Illinois.

may or may not be separated by poorly mineralized, unmineralized, or shaly limestone that ranges in thickness from a fraction of an inch to several feet. The aggregate thickness of the ore beds decreases toward the margins of the deposits. Generally the lower ore beds pinch out first, the upper beds last.

The areal distribution of the principal fluorspar deposits and mineralized trends in the Cave in Rock district, the stratigraphic position of the ore, and the characteristic accessory minerals are shown in Figure 1. The deposits are associated with sets of joint-like fractures and of minor pre-mineral faults that have displacements of less than 20 feet, commonly less than 10 feet, all

trending mainly northeast and northwest. Collectively they form a mineralized belt some 4000 to 5000 feet wide which in a general way parallels the over-all course of the Peters Creek fault zone. This zone, with its aggregate downthrow of at least 500 feet to the northwest, is the largest structural feature in the district. Traces of fluorspar, galena, and sphalerite have been found along this fault, and it is commonly assumed that the mineralizing solutions rose from their source in depth along Peters Creek fault and then spread outward laterally and vertically along minor intersecting faults and fractures.

Structurally there are two general types of deposits, namely those in which the ore is disposed more or less symmetrically on either side of a central zone of fracturing or minor faulting, and those in which the ore lies along one

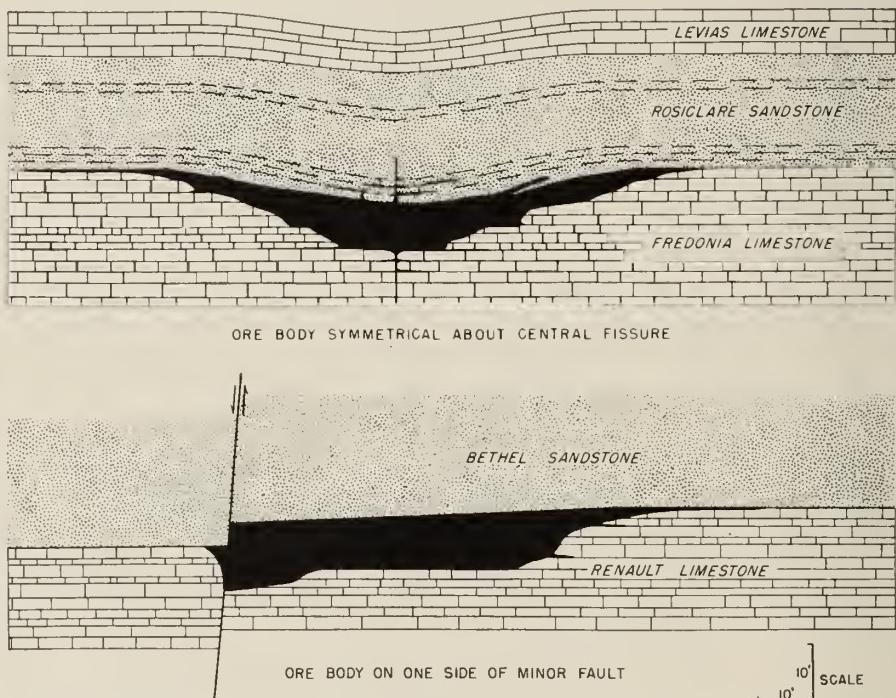


FIG. 2. Schematic cross-sections of the two general types of bedding-replacement fluorspar deposits.

side, generally the upthrow side, of a minor fault. Schematic cross-sections of the two types are shown in Figure 2. In the first type the ore is thickest along or adjacent to the line of axial fracturing and thins toward both margins. Inward-dipping roofs, such as that shown, occur over practically every deposit of this type which is capped by the shaly and relatively incompetent Rosiclar sandstone, but are generally absent where the cap is a structurally competent material like the Fredonia limestone. In the second type the ore is thickest adjacent to the fault and thins toward the far margin. An inward dip of the roof is not so perceptible, although it has been observed in some deposits.

VIEWS OF PREVIOUS INVESTIGATORS.

Previous investigators of the Cave in Rock deposits have generally agreed as to their replacement origin and their localization along joint-like fractures and minor faults. Schwerin and Currier, for example, observed and described certain features suggestive of loss of rock volume such as open spaces between ore and caprock, spalls of caprock entrapped in the underlying ore, and irregular bedding veinlets of fluorspar of the fissure-filling type in shaly roof rock above the ore. To explain these features and also the banded nature of the ore, Schwerin (5, p. 335) proposed the concept that the indicated volume shrinkage took place because of stoichiometric replacement of calcium carbonate by calcium fluoride. This was affirmed later by Currier (3, pp. 44, 45) who also implied that direct solution of limestone in excess of the amount of fluorspar deposited might be an additional cause for shrinkage. Schwerin made no specific reference to the subject, but Currier considered the prominent synclinal sags in the roofs over many deposits to be of structural origin (3, p. 41); he did not recognize that they might have resulted from volume contraction during the ore-forming process as herein postulated.

EVIDENCE OF VOLUME SHRINKAGE.

Evidence gained in recent years from study of extensive mine exposures and records of hundreds of borings not available to earlier investigators indicates clearly that volume shrinkage was a common and characteristic effect of mineralization. A net loss of rock volume during ore formation is indicated by measurable thinning of strata where they have been affected by ore solutions, sagging of strata overlying ore deposits with the formation of solution synclines, transection of the bedding of unplaced limestone by the sloping margins of ore bodies, V-structures on large and small scale within deposits, breccias of roof-rock fragments cemented by fluorspar at the tops of deposits, and the presence of open cavities at the tops and margins of deposits, including extensive tabular open spaces between ore and roof. Data in support of this thesis are presented under three headings, namely evidence from structure maps and cross-sections, from statistics on formation thickness, and from the internal character of the deposits themselves.

Evidence from Structure Maps and Cross-Sections.—Synclines over many deposits are clearly revealed by structural contour maps based on drilling records. One of the most marked of these is shown in Figure 3 by means of contours that show the elevation of the Bethel-Renault contact. The syncline is underlain by mineralized rock in the top of the Renault formation within the area shown by shading, and is bordered by unmineralized ground. This structure has a known length, as illustrated, of 5400 feet, a width of 300 to 700 feet, and a depth of 10 to 40 feet. Some other structures in the district are longer and some are shorter, but in general they are less deep. In the barren areas adjoining these mineralized structures, subsurface contours disclose only gentle dips of uniform character such as that indicated on the right of the syncline in Figure 3.

That this syncline was formed as the result of local thinning of limestone strata in and adjacent to the mineralized zone is illustrated by the cross-section in Figure 4, which was drawn along the line of borings indicated in Figure 3. The borings at both ends of the section are in barren ground whereas the others show a greater or lesser degree of zinc and fluorspar mineralization as indicated, the greatest amount of mineralization being shown by boring No. 10. Above and below the zone most affected by mineralization the strata exhibit

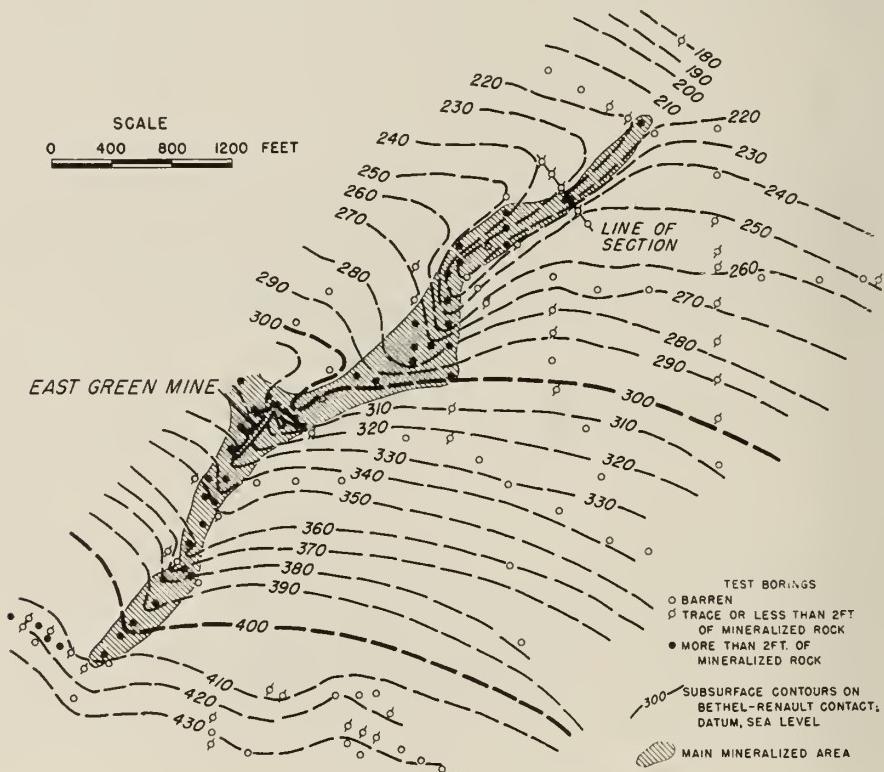


FIG. 3. Typical syncline associated with linear area of mineralization, as revealed by test-drilling.

a uniform slight dip from right to left, whereas within the area of mineralization they dip synclinally toward the center, as shown by their departure from the dashed lines which represent their postulated original position. The synclinal attitude is the result of thinning of the Fredonia, Levias, and Renault limestone formations. Because the thinning is localized in the area of ore formation, it is considered to be the consequence of volume shrinkage that attended the mineralizing process.

Evidence from Statistics on Formation Thickness.—A statistical study of the variation of the interval from the base of the Bethel sandstone to the top of the Fredonia limestone in barren and in mineralized ground shows that the

association of synclines and mineralized ground is a general characteristic of the district. Drill-records from all over the district were used in making the study, the results of which are shown in the three histograms on the left side of Figure 5. Each bar in the histograms records the number of borings in which the reference interval between the base of the Bethel sandstone and the top of the Fredonia limestone is a specified thickness.

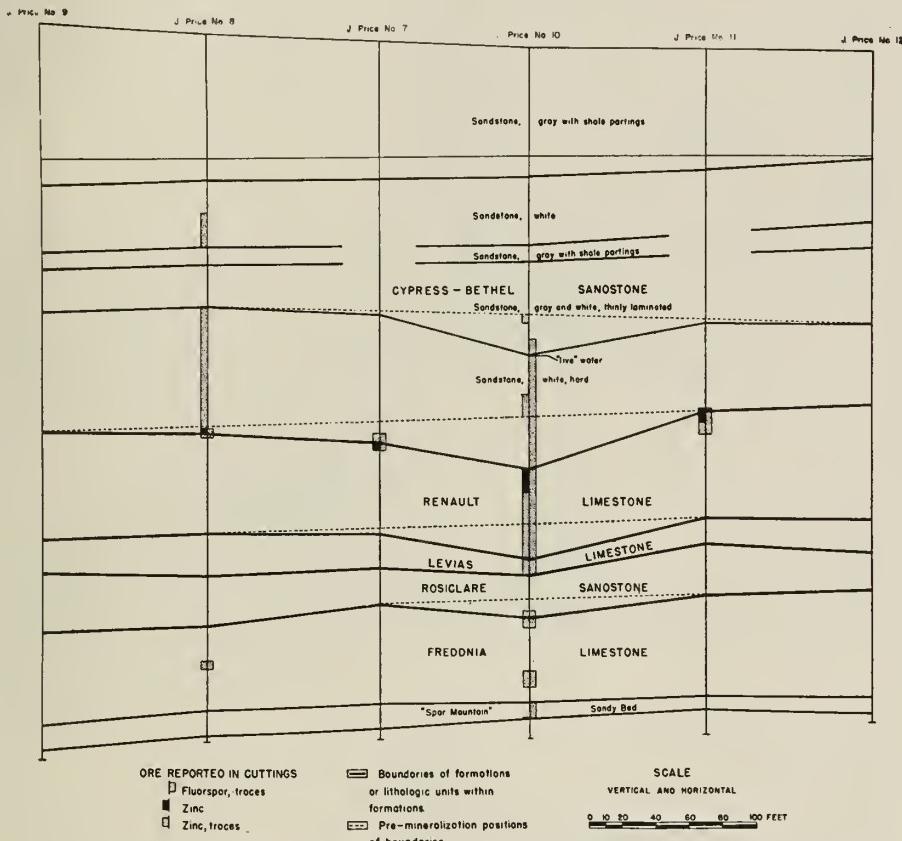


FIG. 4. Cross-section along line of borings indicated in Figure 3, showing that the syncline is restricted to beds affected by mineralization.

In the topmost histogram, representing a group of 383 borings in barren ground, the median thickness of the reference interval is 115 feet as indicated by the black bar. Forty-six percent of the borings had intervals less than, and 45 percent had intervals greater than, the median thickness. The middle histogram represents a group of 121 borings in which the Renault and/or Levias limestones, but not the underlying Fredonia limestone, have been strongly mineralized. In this group 86 percent of the intervals had thicknesses less than the median thickness in barren ground and 11 percent had greater thicknesses. The bottom histogram represents a group of 219 borings

in which strong mineralization has taken place in the Fredonia limestone, but not in the overlying Renault and Levias formations. Here 53 percent of the measured intervals are greater and 41 percent are less than the median value for barren ground.

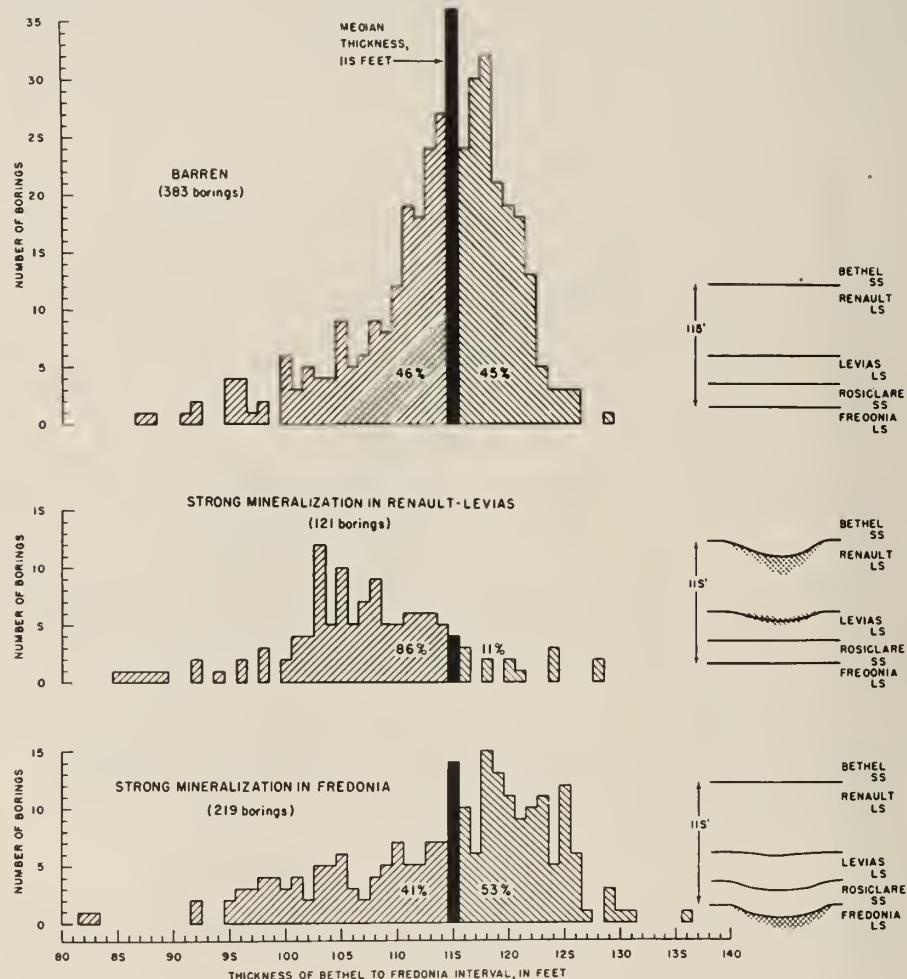


FIG. 5. Histograms and diagrams illustrating relation between thickness of interval from the base of the Bethel sandstone to the top of the Fredonia limestone in borings in barren and mineralized ground. Percentage figures refer to numbers of borings in which the reference interval is larger or smaller than its median thickness in barren ground. Cross-hatched areas in diagrams indicate stratigraphic position of mineralized strata.

The three diagrams to the right of the histograms show what has apparently happened in each case. The upper diagram shows the initial condition in barren ground where the reference interval is 115 feet. The middle diagram

shows mineralized ground in the top of the Renault and Levias limestones, where the consequent sagging of the strata gives rise to a reference interval shorter than in barren ground. The bottom diagram shows that the volume shrinkage and sagging occurred in the top of the Fredonia limestone along with mineral deposition at that level, and because the top of the Renault was unaffected and remained in its original position, the interval was lengthened to more than its original value.

Evidence from Internal Characteristics of the Deposits.—Numerous small-scale features of the deposits also confirm the idea of volume loss during mineralization, and afford an understanding of the mechanism involved.

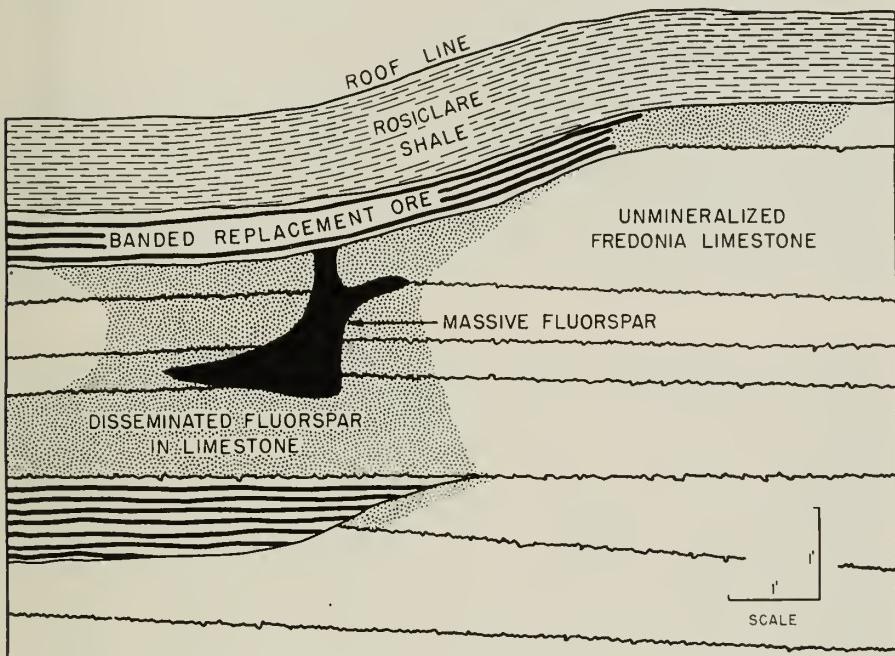


FIG. 6. Scale drawing of typical relations at the edge of a bedding-replacement ore body. The shaly caprock dips sharply at the edge of the deposit, in contrast to the nearby horizontal attitude of the underlying beds as shown by stylolitic bedding planes (irregular horizontal lines). Part of the topmost bed of limestone has been removed by solution which has allowed the overlying beds to sag.

Figure 6 is a scale drawing of the marginal portion of a particular ore body, but the relations are typical of many other deposits in the district. Of significance is the flat-lying character of the unmineralized Fredonia limestone, indicated by the horizontal stylolitic bedding planes, which contrasts with the sharp dip of the thin bed of banded replacement ore and the shale caprock at the edge of the deposit. The sharp dip is clearly the result of subsidence that followed the solution and removal of more than half of the thick limestone bed below the thin bed of ore. The same situation is shown in miniature in

Figure 7. The horizontal bedding of the limestone is apparent on the left above and below the hammer. The dark-colored V-shaped mass in the center, whose sloping margins sharply transect the limestone bedding, may be considered the equivalent of an ore body. The light-colored lenticular bodies within the V-shaped mass are barite which originally were part of a thin band at the base of the overlying limestone stratum, but which sagged down as limestone was dissolved and came to rest on a bed consisting of clay and small masses of soft, partially leached limestone, clearly a residue from the solution of the limestone. The material above the barite is a structureless, plastic, sandy red clay, similar to the surface residual clay of the region, that was brought by groundwater through crevices into the space left above the barite band. The overlying limestone could not sag into the space because of its rigidity and the short span left unsupported.

Figure 8 shows part of a mine pillar. The inward dipping slabs of partly or wholly replaced limestone beneath an essentially flat undisturbed roof indicate collapse brecciation following active local solution and removal of part of the original limestone. Similar structures are common at the tops of ore bodies, where fragments of the caprock spalled off into solution or subsidence openings and became cemented by massive fluorspar that was deposited around them. In portions of some ore bodies in the top beds of the Fredonia limestone, solution collapse has carried fragments of the overlying thin-bedded and shaly Rosiclare sandstone as much as 20 feet below their original level. These extreme cases occur typically in narrow linear zones that follow the courses of joint-like fractures which apparently allowed free circulation of the ore-bearing solutions, and consequently an extra-normal amount of solution of the limestone.

Figure 9 shows a portion of another mine pillar in which a 1-inch fine-grained band has split off from the base of a bed of banded replacement ore and slopes down into a body of light-colored massive fluorspar. This is evidence of the sagging of a rock layer into a former opening that was made by solution of limestone and subsequently filled with fluorspar. The same process is believed to account for the manner in which banded ore in some exposures dips inward and downward more or less symmetrically on the two sides of vertical veinlets of fluorspar, producing V-shaped structures like that shown in Figure 10. Massive fluorite, which appears dark in the photograph, fills the space next to the roof left open by the sagging above the V-structure. Bastin (1, pp. 47, 48) observed and prepared sketches of the same structures, including one W-shaped, but attributed their formation to rhythmic banding produced

FIG. 7. Small structure illustrating relations present on a large scale in fluorite deposits. Dark-colored V-shaped mass is largely clay, in which lenticular masses of white barite are remnants of a band of barite formerly located at the top of the "V." Solution of limestone below the barite allowed the latter to sag into its present position. Photograph of adit wall.

FIG. 8. Steeply dipping slabs of mineralized rock below undisturbed roof imply collapse into a zone where mineralizing solutions removed much of the original limestone. Light-colored areas are mainly coarsely crystalline fluorspar. Photograph of mine pillar.

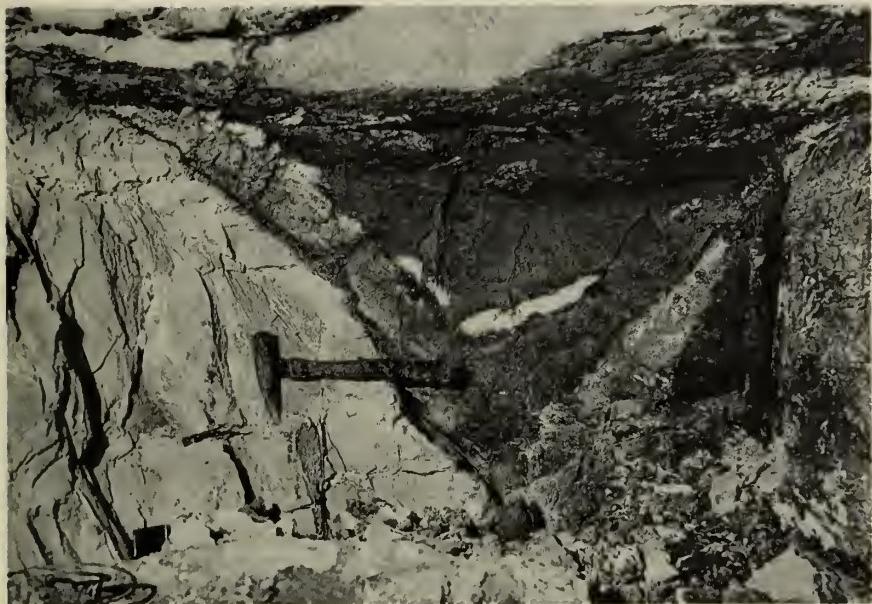


FIG. 7



FIG. 8

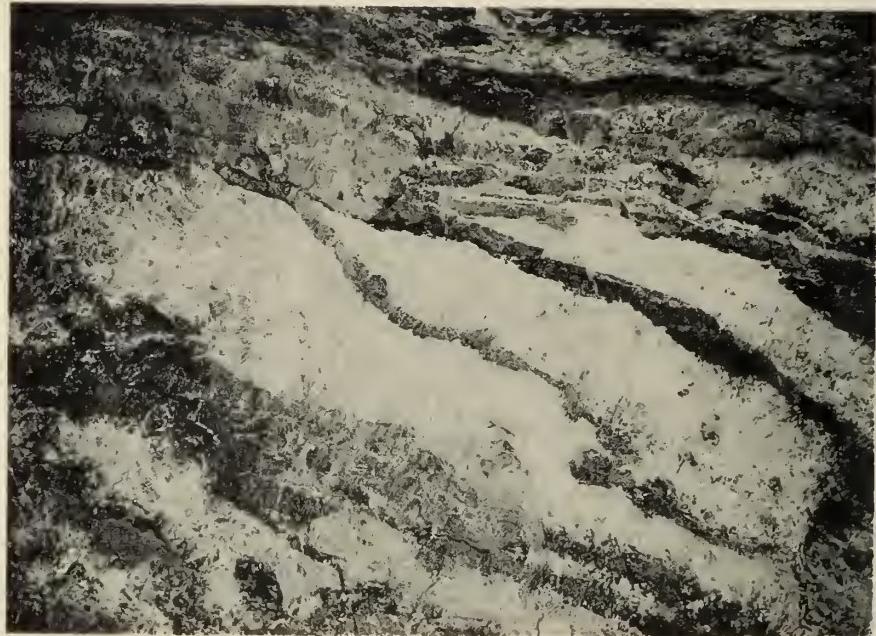


FIG. 9



FIG. 10

by diffusion of ore solutions outward from the central fractures, which was in line with his hypothesis that all the banded ore was the result of rhythmic diffusion banding. The prevalence of solution and volume shrinkage effects herein described, as well as Currier's (3, pp. 36-39) generally more satisfactory explanations for the origin of the banded ore, tend to make Bastin's views less tenable. Probably most of the distortion of the lamination in ore beds, beyond that attributable to cross-bedding in the original limestone, may be explained as the result of solution and shrinkage during mineralization.

Still other evidence of solution shrinkage is afforded by the cavities lined with crystals and the masses of massive fluorite representing completely filled cavities which are abundant, especially at the tops and margins of many deposits, and by the open spaces from half an inch to a foot wide that in some places extend over hundreds of square feet between the base of the caprock and the top of the ore. These were voids formed by uncompensated loss in rock volume.

MECHANISM RESPONSIBLE FOR VOLUME SHRINKAGE.

The mechanism responsible for the foregoing phenomena appears to be a combination of volume reduction owing to stoichiometric replacement of the calcite in limestone by denser fluorite, and of volume loss due to actual removal of limestone by the action of solvent mineralizing fluids.

Theoretically the volume reduction from stoichiometric replacement could amount to as much as 33 percent, for 100 grams of calcium made into fluorite occupies only two-thirds of the volume required by 100 grams of calcium made into calcite. The properties of the limestone and the ore produced from it indicate that this optimum shrinkage rarely occurred except in local situations, for none of the limestone is pure, replacement is rarely if ever complete except in small areas, and the ore is practically always more porous than the original limestone.

Removal of limestone through solution by the ore-forming fluids may have been a large or small contributor to the total loss in volume. Large effects are easily recognized, such as situations in which fragments of the caprock are found 20 feet or more below their original position, or limestone beds are visibly truncated, but much material may have been lost from a limestone bed without the evidence being clearly preserved in the resulting bed of ore. In some places strong synclinal effects are present even though no great amount of fluorspar has been formed. In such places a large share of the volume loss must be attributed solely to solution of limestone.

FIG. 9. Layers of dark-colored ore sloping downward into a mass of light-colored coarse fluorite indicate collapse of rock layers into former opening now filled with mineral. Scale is shown by mark of drill in banded ore at upper left. Photograph of mine pillar.

FIG. 10. Structure at upper left is a typical "V" centering about a vertical fissure. Such structures are believed to have formed by the symmetrical sagging of numerous thin rock layers into a zone of active solution along the central fissure. Note the two dark-colored areas on either side of the fissure at the top of the "V," which are crystal-lined cavities formed by the sagging of the layers below. Photograph of wall of mine.

CONCLUSION.

It is concluded that the following chronological events explain the phenomena described and indicate the probable relations of structure to the formation of the Cave in Rock deposits:

1. Major normal faulting along the Peters Creek fault zone.
2. Formation of northeast and northwest sets of fractures and minor faults, possibly coincidental with movement along the Peters Creek fault zone, perhaps later.
3. Rise of moderate-temperature mineralizing solutions from depth, probably along the Peters Creek fault.
4. Spreading out of solutions from the Peters Creek fault into and upward along certain of the sets of supplemental fractures and minor faults which were probably connected with it. Possibly solutions rose along only a few main channelways and then spread laterally to a considerable extent.
5. Replacement and chemical solution of limestone strata which were more readily attacked than others by reason of greater porosity or larger pores, or because they were more shattered in the preceding period of fracturing associated with the development of the Peters Creek fault. Probably the deposits formed wherever further upward or lateral movement of solutions was restricted by lack of suitable continuous channel-ways.
6. In the mineralizing process a denser mineral was substituted for one less dense, and more material was removed than was added by the solutions, resulting in a net loss in rock volume at the sites of mineral deposition. Subsidence of the overlying beds accompanied and followed this process, producing solution synclines.

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